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None

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(54) **Producing an integrally bladed rotor**

(57) An apparatus for producing an integrally bladed compressor rotor from a disc shaped workpiece comprises two annular cutters 20, 30 rotatable about respective axes 21, 31. The axes 21, 31 of the annular cutters 20, 30 are parallel and one annular cutter 30 surrounds the other annular cutter 20. A disc shaped workpiece 14 is placed on a workpiece holder and the workpiece holder moves the workpiece 14 axially relative to the annular cutters 20, 30 so that the annular cutter 20 cuts out material at the periphery of the workpiece 14 to form a concave aerofoil surface of a blade 16 and the annular cutter 30 cuts out material at the periphery of the workpiece 14 to form a convex aerofoil surface of the blade 16. The annular cutters 20, 30 are moved relatively while their axes 21, 31 remain parallel by a pair of rotating cams 56, 62 so that the shapes of the concave and convex aerofoil surfaces of the blade 16 may be varied.

Fig.1

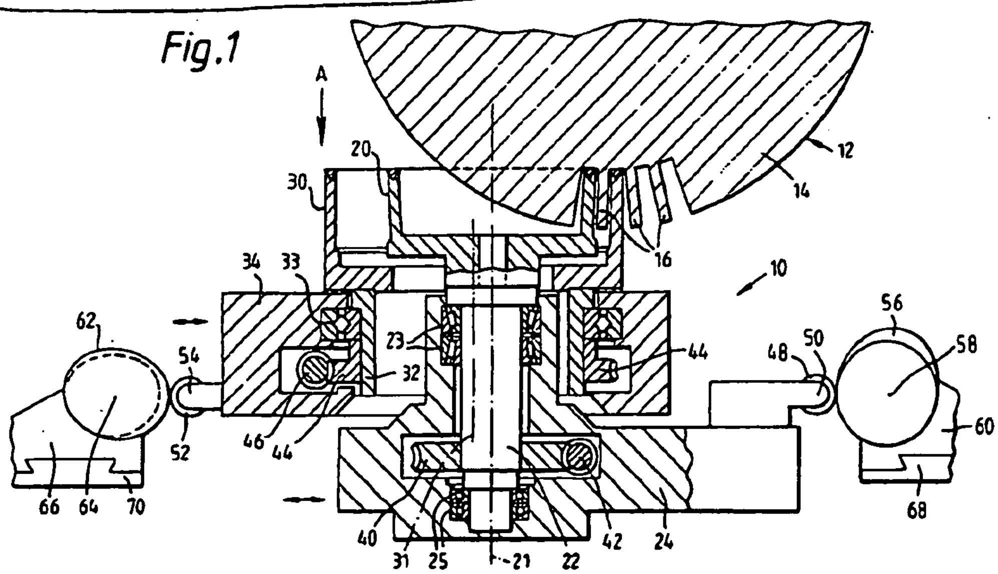

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Fig. 2

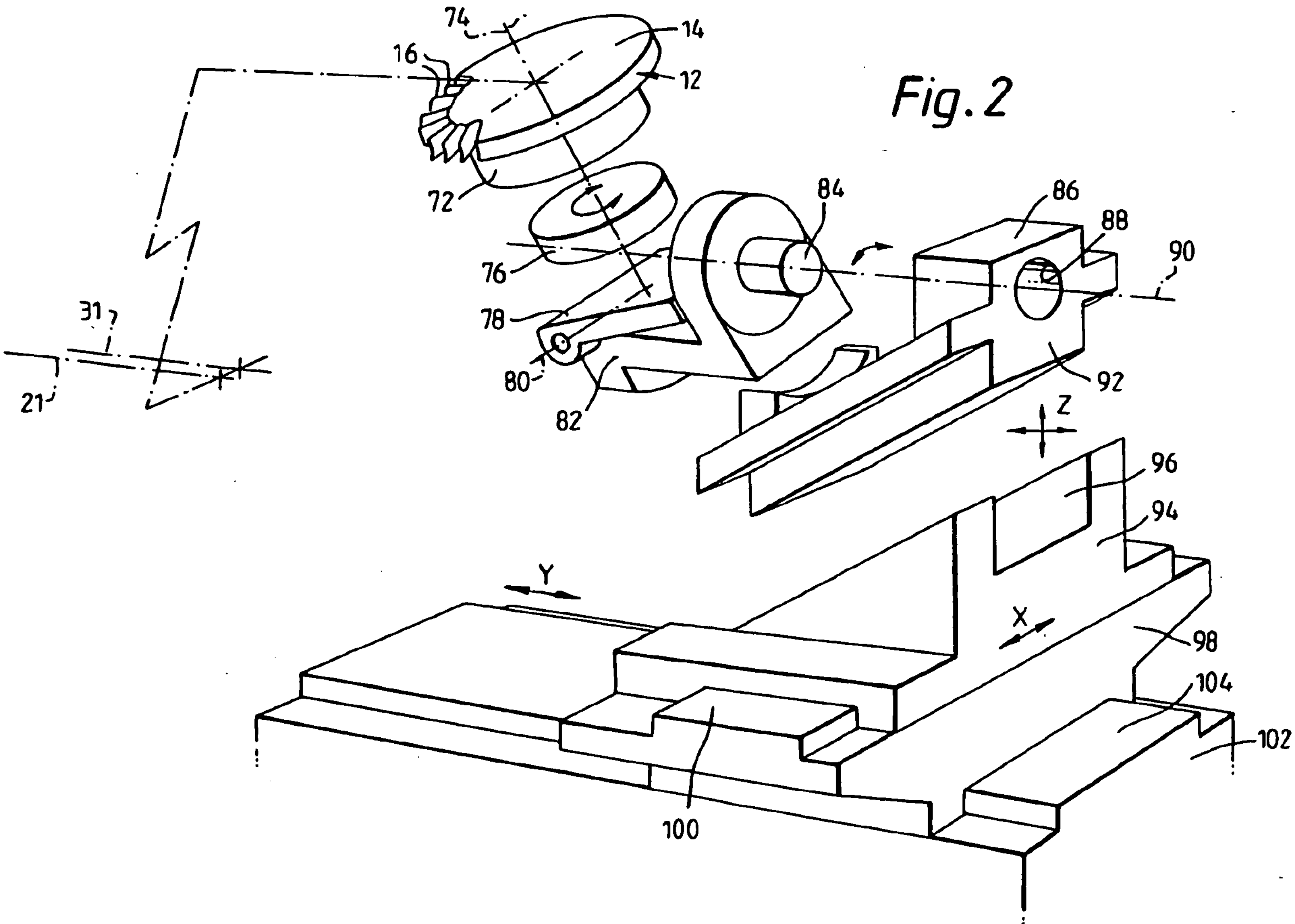
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Fig. 3

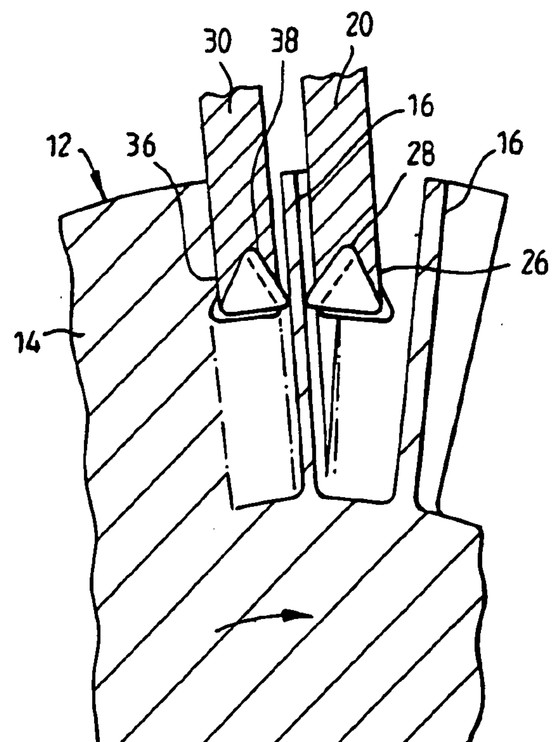
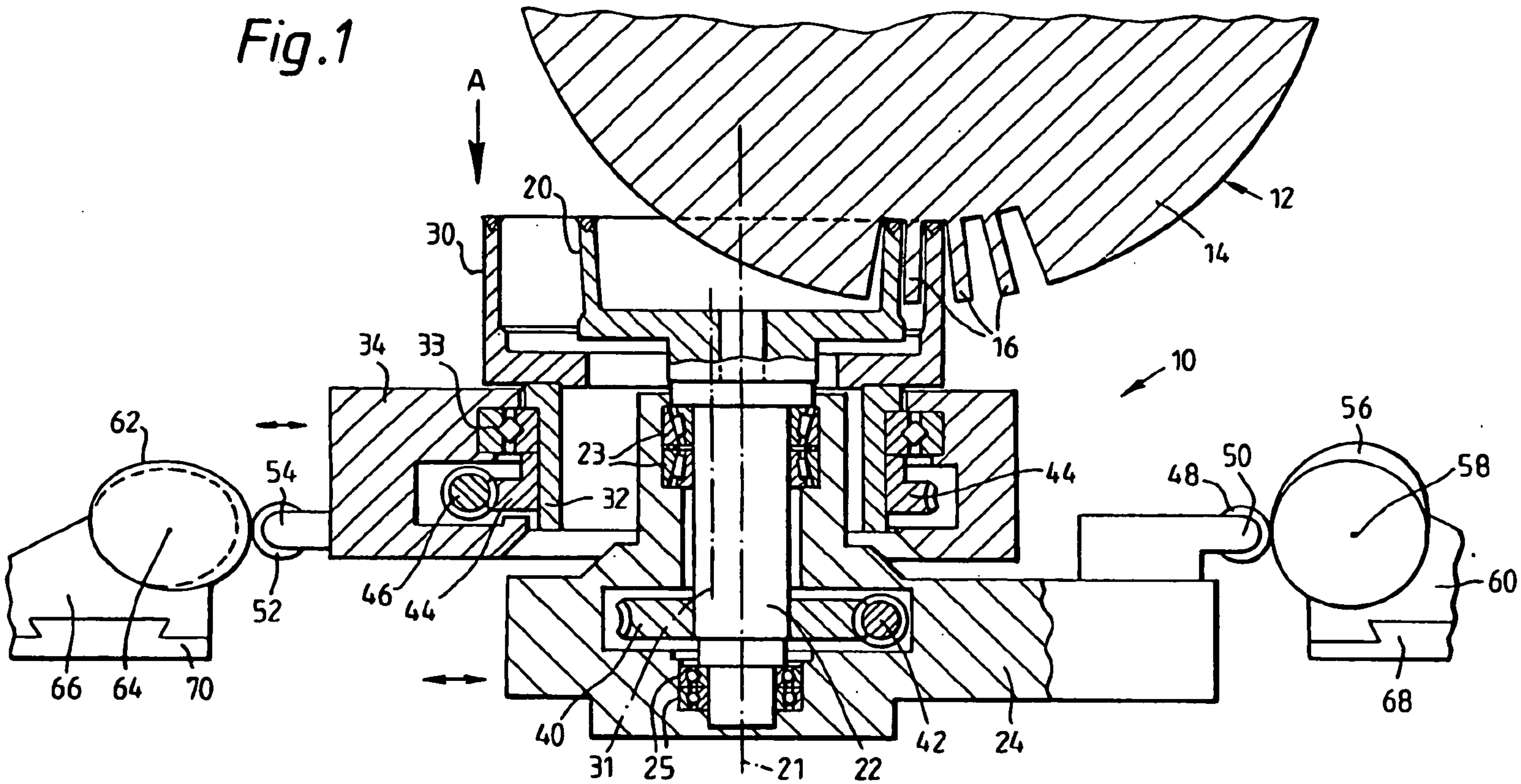


Fig.1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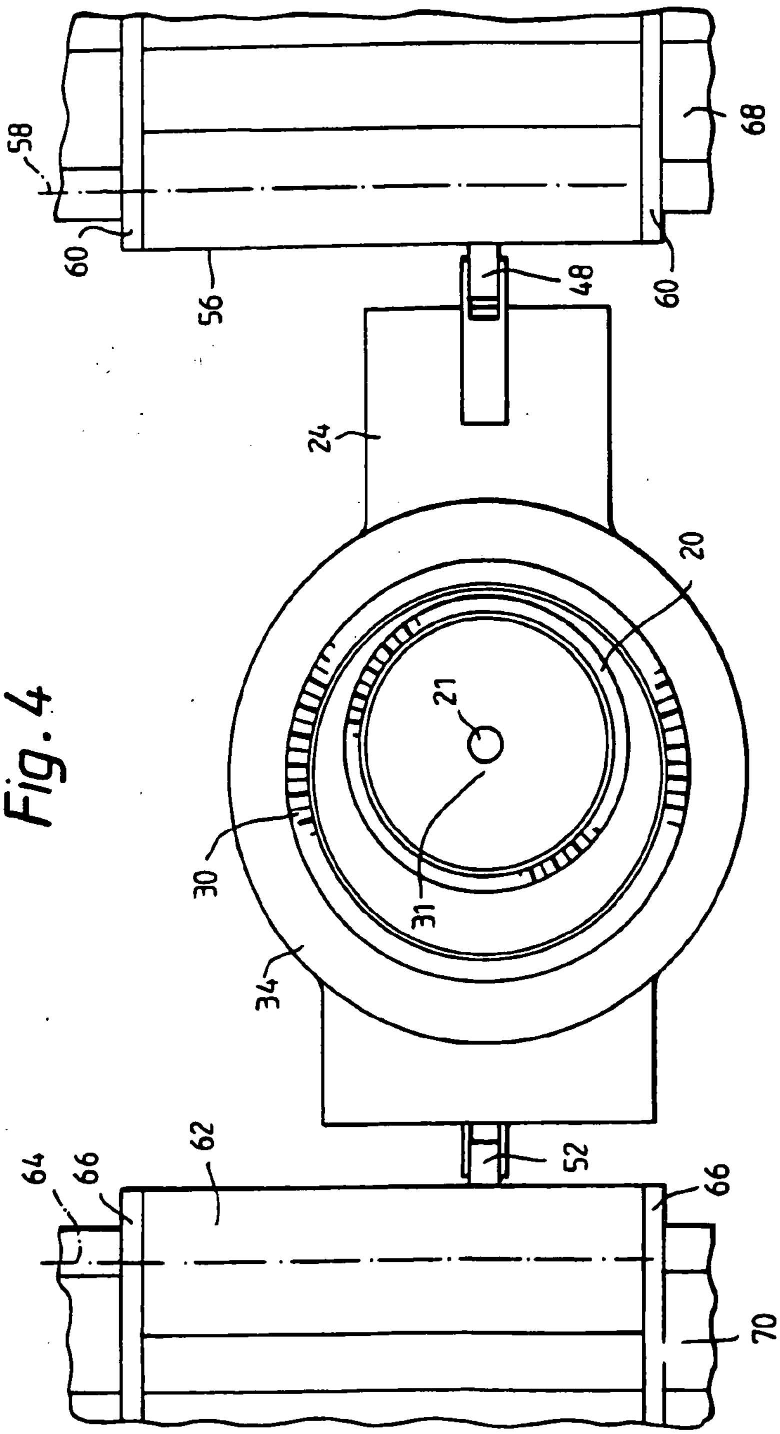

Fig. 4

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A METHOD AND APPARATUS FOR PRODUCING AN INTEGRALLY BLADED ROTOR

The present invention relates to a method and an apparatus for producing integrally bladed rotors, particularly for producing integrally bladed compressor rotors for gas turbine engines.

Accordingly the present invention provides an apparatus for producing an integrally bladed rotor from a disc shaped workpiece, comprising:-

a first annular cutter rotatably mounted on a first carrier, first drive means to rotate the first annular cutter relative to the first carrier,

a second annular cutter rotatably mounted on a second carrier, second drive means to rotate the second annular cutter relative to the second carrier,

the first annular cutter and the second annular cutter being arranged such that their axes of rotation are parallel, the inner diameter of the second annular cutter being greater than the outer diameter of the first annular cutter, the second annular cutter being arranged to surround the first annular cutter,

a workpiece holder, means to produce relative movement between the workpiece holder and the first and second annular cutters so as to cut out material at the periphery of any said workpiece to form a blade.

Preferably the first annular cutter has a plurality of teeth at the end adjacent the workpiece holder.

Preferably a number of first teeth of the first annular cutter are end cutting teeth and a number of second teeth are end and outside cutting teeth.

Preferably the first teeth and the second teeth are arranged alternately throughout the circumference of the first annular cutter.

Preferably the second annular cutter has a plurality of teeth at its end adjacent the workpiece holder.

Preferably a number of first teeth of the second annular cutter are end cutting teeth and a number of second teeth are end and inside cutting teeth.

Preferably the first teeth and the second teeth are arranged alternately throughout the circumference of the second annular cutter.

Preferably the apparatus includes means to move the first annular cutter and second annular cutter relatively such that their rotational axes move relatively while remaining parallel.

Preferably a third drive means moves the first annular cutter linearly.

Preferably the third drive means comprises a first rotatable cam which abuts a first follower on the first carrier.

Preferably a fourth drive means moves the second annular cutter linearly.

Preferably the fourth drive means comprises a second rotatable cam which abuts a second follower on the second carrier.

Preferably the first rotatable cam is a three dimensional cam, the first rotatable cam is movable linearly along its axis of rotation.

Preferably the second rotatable cam is a three dimensional cam, the second rotatable cam is movable linearly along its axis of rotation.

Preferably the workpiece holder comprises an indexing table which is rotatably mounted about an axis on a first member.

Preferably the indexing table is mounted on a first member which is pivotable about a tilting axis on a second member, the titling axis is in a plane perpendicular to the axes of rotation of the first and second annular cutters.

Preferably the second member is rotatably mounted on a third member about an axis parallel to the axes of rotation of the first and second annular cutters.

Preferably the apparatus includes means to synchronise the rotation of the first rotatable cam with the rotation of the first annular cutter and the spacing between the second teeth.

Preferably the apparatus includes means to synchronise the rotation of the second rotatable cam with the rotation of the second annular cutter and the spacing between the second teeth.

Preferably the apparatus includes means to synchronise linear movement of the first rotatable cam with the relative axial movement of the first and second cutters and the workpiece holder

Preferably the apparatus includes means to synchronise linear movement of the second rotatable cam with the relative axial movement of the first and second cutters and the workpiece holder.

The present invention also provides a method for producing an integrally bladed rotor from a disc shaped workpiece, comprising:-

rotating a first annular cutter about a first axis of rotation, rotating a second annular cutter about a second axis of rotation, the first and second annular cutters being arranged such their axes of rotation are parallel, the inner diameter of the second annular cutter being greater than the outer diameter of the first annular cutter, the second annular cutter being arranged to surround the first annular cutter.

moving the first and second annular cutters and the disc shaped workpiece axially relatively such that the first annular cutter cuts a concave aerofoil shaped surface of a blade and the second annular cutter cuts a convex aerofoil shaped surface of the blade in the periphery of the disc shaped workpiece.

Preferably the method includes moving the first annular cutter and the second annular cutter relatively such that their rotational axes move relatively while remaining parallel to vary the shapes of the concave and

convex aerofoil shaped surfaces of the blade.

Preferably the method includes rotating the workpiece through a predetermined angle about its axis in order to cut another blade.

Preferably the method includes rotating the workpiece around the mean axis of the blade being cut by the first and second annular cutters such that the optimum match between cutter radius and twist of the blade is maintained.

Preferably the method includes initially tilting the workpiece such that the first and second annular cutters cut the blade root.

The invention will be more fully described by way of example with reference to the accompanying drawings in which:-

Fig 1 is a cross-sectional view through part of an apparatus for producing an integrally bladed rotor according to the present invention.

Fig 2 is an exploded perspective view of part of the apparatus shown in Fig 1.

Fig 3 is an enlarged cross-sectional view of part of the apparatus shown in Fig 1.

Fig 4 is a view in the direction of arrows A in Fig 1.

An apparatus 10 for producing an integrally bladed rotor from a disc shaped workpiece is shown in figures 1 to 4. The integrally bladed rotor comprises a rotor disc which has a plurality of equi-angularly spaced, radially outwardly extending blades formed integrally therewith.

The apparatus 10 comprises a first annular cutter 20 and a second annular cutter 30. A first spindle 22 is secured to the first annular cutter 20, and the first annular cutter 20 is rotatably mounted about a rotational axis 21 in a first carrier 24 by axially spaced bearings 23 and 25. The first annular cutter 20 has a number of teeth 26 and 28. The teeth 26 and 28 are staggered and are arranged alternately throughout the circumference of

the first annular cutter 20. The teeth 26 are end cutting teeth, and the teeth 28 are end and side cutting teeth. The first annular cutter 20 has an axial length greater than the radial length of the blades to be cut on a rotor disc blank 14. A second spindle 32 is secured to the second annular cutter 30 and the second annular cutter 30 is rotatably mounted, about rotational axis 31, in a second carrier 34 by a bearing 33. The second annular cutter 30 has a number of teeth 36 and 38. The teeth 36 and 38 are staggered and are arranged alternately throughout the circumference of the second annular cutter 30. The teeth 36 are end cutting teeth, and the teeth 38 are end and side cutting teeth. The second annular cutter 30 has an axial length greater than the radial length of the blades 16 to be cut on the rotor disc blank 14.

The first annular cutter 20 and the second annular cutter 30 are arranged so that their rotational axes 21 and 31 respectively are parallel. The inner diameter of the second annular cutter 30 is greater than the outer diameter of the first annular cutter 20 and the second annular cutter 30 surrounds the first annular cutter 20.

A first motor (not shown) is provided to drive the first annular cutter 20 relative to the first carrier 24 and a second motor (not shown) is provided to drive the second annular cutter 30 relative to the second carrier 34. A first sun gear 40 is secured to the first spindle 22 and the first sun gear 40 is driven by the first motor <u>via</u> a gear 42. A second sun gear 44 is secured to the spindle 32 and the second sun gear 44 is driven by the second motor <u>via</u> a gear 46.

The first carrier 24 has a first cam follower 48 which is rotatably mounted on the first carrier 24 about axis 50. Similarly the second carrier 34 has a second cam follower 52 which is rotatably mounted on the second carrier 34 about axis 54. The first cam follower 48 abuts against a first cam 56. The first cam 56 is

rotatably mounted about axis 58 on a first cam holder 60. The first cam holder 60 is itself movable linearly in the direction of the axis 58 of the first cam 56. The first cam 56 is a three dimensional cam and has variations in its profile both circumferentially and axially. Similarly the second cam follower 52 abuts against a second cam 62. The second cam 62 is rotatably mounted about an axis 64 on a second cam holder 66. The second cam holder 66 is movable linearly in the direction of the axes 64 of the second cam 62. The second cam 62 is also a three dimensional cam and has variations in its profile both circumferentially and axially. The axes 58 and 64 are parallel, and are arranged in a plane perpendicular to the axes 21 and 31. The first cam holder 60 is movable along a first track 68 and the second cam holder 66 is movable along a second track 70.

The apparatus 10 also comprises a workpiece holder 72 upon which the disc shaped workpiece, or rotor disc blank, 14 is placed in order to machine blades at the periphery of the rotor disc blank 14. The workpiece holder 72 is mounted on an indexing table 76 which is rotatably mounted about an axis 74, on a first member 78. The first member 78 is pivotally mounted about an axis 80 on a second member 82, the axis 80 is perpendicular to the axis 74. The second member 82 is rotatably mounted about an axis 90, on a third member 86. The second member 82 has a spindle 84 which is rotatably mounted in an aperture 88 in the third member 86. The axis 90 is in the same plane as the axis 74 and is parallel to the axes 21 and 31. The third member 86 has an inclined slide 92 which locates on a third inclined track 96 on a fourth member 94. The fourth member 94 is movable along a fourth track 100 on a fifth member 98. The fourth track 100 is arranged to extend in a direction in a plane perpendicular to the axis 90. The fifth member 98 is movable along a fifth track 104 on a base member 102. The fifth track 104 is arranged in a plane perpendicular

to the fourth track 100 and parallel to the axis 90 of rotation of the first and second annular cutters 20 and 30 respectively.

In operation a disc shaped workpiece, or rotor disc blank, 14 is placed upon the workpiece holder 72. The disc shaped workpiece 14 may be either circular or may have a plurality of equi-circumferentially spaced, radially extending, slots machined on its periphery.

The periphery of the workpiece 14 is moved into the first and second annular cutters 20 and 30 respectively by controlled movement of the fifth member 98 relative to the base member 102 along track 104 and by movement of the third member 86 relative to the fourth member 94 along the inclined track 96. The principal movement is the movement of the fifth member 98 relative to the base member 102, but movement of the fifth member 98 relative to the base member 102 is used to cancel any movement of the third member 86 relative to the fourth member 94 along the inclined track 96 which is used to adjust the vertical position.

The second annular cutter 30 cuts the convex aerofoil shaped surface of a blade with its insides cutting teeth 38 and the first annular cutter 20 cuts the concave aerofoil shaped surface of the blade with its outside cutting teeth 28. The bulk of the material is removed from the periphery of the workpiece 14 by the end cutting teeth 36 on the second annular cutter 30 and the end cutting teeth 26 on the first annular cutter 20. The teeth 28 and 38 cut a radius equal to the cutter radius and this is approximately the required aerofoil shapes.

The rotation of the first and second cams 56 and 62 is synchronised with the rotation of the first and second annular cutters 20 and 30 respectively and the tooth spacing in order to move the first and second annular cutters 20 and 30 in the plane containing their axes such that these movements modify the cutting radius to the required convex and concave aerofoil shapes required

during the passage of the teeth 28 and 38 respectively. Less than half of the cam rotation generates the aerofoil shape, the remaining cam rotation is the return stroke and the time that the teeth 26 and 36 are cutting.

The first and second cams 56 and 62 are moved progressively along the tracks 68 and 70 respectively in order to move the cam followers 48 and 52 contact plane along the cam axis as the cutters 20 and 30 move further from the top of the blade to the root of the blade such that a variation in the aerofoil shape is produced for both the convex and concave aerofoil shaped surfaces. The cams 56 and 62 are preferably several times longer than the aerofoil it represents in order to give better conditions for the cam follower rollers 42 and 52 respectively. The axial movement of the cams 56 and 62 is synchronised with the movement of the fifth member 98 along the track 104 which feeds the rotor disc blank, or disc shaped workpiece, 14 to the cutters 20 and 30.

The rotor disc blank, disc shaped workpiece, 14 is rotated around the mean axis of the blade being cut, so that the optimum match between cutter radius and twist of the aerofoil is maintained. The mean axis of the blade being cut preferably is arranged coaxial with axis 90 by appropriate positioning of the index table 76 and having the workpiece holder 72 at the appropriate height. If this cannot be achieved, further movement to optimise the cutter blade relationship is obtained from the movement in the vertical (Z) and horizontal (X) axes. These movements are synchronised with rotation about axis 90 and the position of the cutters 20 and 30 along the length of the blade. This is achieved by rotating the second member 82 about axis 90 on the third member 86 by moving the fourth member 84 in the appropriate direction along track 100, by moving the third member 86 in the appropriate direction along inclined track 96 and by moving the fifth member 98 in the appropriate direction along track 104.

The root platforms are generally part of a cone and in order to produce the root platforms the rotor disc blank 14 is tilted by pivoting the first member 78 about the axis 80 so that the teeth 26 and 36 of the cutters 20 are 30 ~~respectively~~ semi finish the platform and finish the aerofoil root.

When the blade is finished the indexing table is rotated through a predetermined angle and the process is repeated to produce another blade 16 on the disc shaped workpiece, or rotor disc blank, 14.

The productivity of this machine is limited by the rate the cutters 20 and 30 follow the cams 56 and 62 respectively. Up to 300 cycles per minute is possible for the apparatus. It is estimated that a 30 mm long blade and adjacent platforms may be machined in 90 seconds. If blades of 75 mm length and 40 to 45 mm chordal length are produced by the machine, assuming 0.1 mm cut per tooth 26, 36 and 250 cuts per minute each blade would be produced in 3 minutes. The machine is much quicker at producing integrally bladed rotor discs that present machines. The machine may be used to produce integrally bladed compressor rotor discs and integrally bladed turbine rotor discs for gas turbine engines or integrally bladed rotor discs of steam turbines. The integrally bladed turbine rotor discs must be of the low pressure stages where cooling of the blades is not required.

Following the process performed by the apparatus the leading and trailing edges of the blades 16 are finish machined and further machining and polishing of the root platform is carried out. The finish of the blades after the process performed by the apparatus is better than that produced by present machines, the finish is more like a turned finish than a milled finish.

The rotation of the first and second cutters 20 and 30 respectively is preferably synchronised so that the finishing teeth 28 and 38 cut at the same time, so that the deflection of the blade under side cutting forces is

balanced and minimised.

The use of an inclined slide 92 and inclined track 96 to give the small vertical movements is preferred, but it is possible to use a separate vertical slide. However this would result in several of the axes of movement being overhanging and being unsupported from the slideway.

Claims:-

1. An apparatus for producing an integrally bladed rotor from a disc shaped workpiece, comprising:-

a first annular cutter rotatably mounted on a first carrier, first drive means to rotate the first annular cutter relative to the first carrier,

a second annular cutter rotatably mounted on a second carrier, second drive means to rotate the second annular cutter relative to the second carrier,

the first annular cutter and the second annular cutter being arranged such that their axes of rotation are parallel, the inner diameter of the second annular cutter being greater than the outer diameter of the first annular cutter, the second annular cutter being arranged to surround the first annular cutter,

a workpiece holder, means to produce relative axial movement between the workpiece holder and the first and second annular cutters so as to cut out material at the periphery of any said workpiece to form a blade.

2. An apparatus as claimed in claim 1 wherein the first annular cutter has a plurality of teeth at the end adjacent the workpiece holder.

3. An apparatus as claimed in claim 2 wherein a number of first teeth of the first annular cutter are end cutting teeth and a number of second teeth are end and outside cutting teeth.

4. An apparatus as claimed in claim 3 wherein the first teeth and the second teeth are arranged alternately throughout the circumference of the first annular cutter.

5. An apparatus as claimed in any of claims 1 to 4 wherein the second annular cutter has a plurality of teeth at its end adjacent the workpiece holder.

6. An apparatus as claimed in claim 5 wherein a number of first teeth of the second annular cutter are end cutting teeth and a number of second teeth are end and inside cutting teeth.

7. An apparatus as claimed in claim 6 wherein the first teeth and the second teeth are arranged alternately throughout the circumference of the second annular cutter.

8. An apparatus as claimed in any of claims 1 to 7 including means to move the first annular cutter and second annular cutter relatively such that their rotational axes move relatively while remaining parallel.

9. An apparatus as claimed in claim 8 wherein a third drive means moves the first annular cutter linearly.

10. An apparatus as claimed in claim 9 wherein the third drive means comprises a first rotatable cam which abuts a first follower on the first carrier.

11. An apparatus as claimed in any of claims 8 to 10 wherein a fourth drive means moves the second annular cutter linearly.

12. An apparatus as claimed in claim 11 wherein the fourth drive means comprises a second rotatable cam which abuts a second follower on the second carrier.

13. An apparatus as claimed in claim 10 in which the first rotatable cam is a three dimensional cam, the first rotatable cam is movable linearly along its axis of rotation.

14. An apparatus as claimed in claim 12 in which the second rotatable cam is a three dimensional cam, the second rotatable cam is movable linearly along its axis of rotation.

15. An apparatus as claimed in any of claims 1 to 14 wherein the workpiece holder comprises an indexing table which is rotatably mounted about an axis on a first member.

16. An apparatus as claimed in claim 15 wherein the indexing table is mounted on a first member which is pivotable about a tilting axis on a second member, the tilting axis is in a plane perpendicular to the axes of rotation of the first and second annular cutters.

17. An apparatus as claimed in claim 16 wherein the second member is rotatably mounted on a third member about an axis parallel to the axes of rotation of the first and second annular cutters.

18. An apparatus as claimed in claim 10 or claim 13 when dependent upon claim 3 or claim 4 including means to synchronise the rotation of the first rotatable cam with the rotation of the first annular cutter and the spacing between the second teeth.

19. An apparatus as claimed in claim 12 or claim 14 when dependent upon claim 6 or claim 7 including means to synchronise the rotation of the second rotatable cam with the rotation of the second annular cutter and the spacing between the second teeth.

20. An apparatus as claimed in claim 18 including means to synchronise linear movement of the first rotatable cam with the relative axial movement of the first and second cutters and the workpiece holder.

21. An apparatus as claimed in claim 19 including means to synchronise linear movement of the second rotatable cam with the relative axial movement of the first and second cutters and the workpiece holder.

22. An apparatus as claimed in claim 17 wherein the third member is mounted on a fourth member such that the third member is moveable with a first directional component parallel to the axes of rotation of the first and second annular cutters and is moveable with a second directional component in the plane perpendicular to the axes of rotation of the first and second annular cutters.

23. An apparatus as claimed in claim 22 wherein the fourth member is mounted on a fifth member such that the fourth member is movable in a plane perpendicular to the axes of rotation of the first and second annular cutters.

24. An apparatus as claimed in claim 23 wherein the fifth member is mounted on a base member such that the fifth member is movable in a direction parallel to the axes of rotation of the first and second annular cutters.

25. A method for producing an integrally bladed rotor from a disc shaped workpiece, comprising

rotating a first annular cutter about a first axis of rotation, rotating a second annular cutter about a second axis of rotation, the first and second annular cutters being arranged such their axes of rotation are parallel, the inner diameter of the second annular cutter being greater than the outer diameter of the first annular cutter, the second annular cutter being arranged to surround the first annular cutter,

moving the first and second annular cutters and the disc shaped workpiece axially relatively such that the first annular cutter cuts a concave aerofoil shaped surface of a blade and the second annular cutter cuts a convex aerofoil shaped surface of the blade in the periphery of the disc shaped workpiece.

26. A method as claimed in claim 25 including moving the first annular cutter and the second annular cutter relatively such that their rotational axes move relatively while remaining parallel to vary the shapes of the concave and convex aerofoil shaped surfaces of the blade.

27. A method as claimed in claim 25 or claim 26 including rotating the workpiece through a predetermined angle about its axis in order to cut another blade.

28. A method as claimed in claim 25, claim 26 or claim 27 including rotating the workpiece around the mean axis of the blade being cut by the first and second annular cutters such that the optimum match between cutter radius and twist of the blade is maintained.

29. A method as claimed in claim 25, claim 26, claim 27 or claim 28 including initially tilting the workpiece such that the first and second annular cutters cut the blade root.

30. A method as claimed in any of claims 25 to 29 including machining at least one radially extending slot in the periphery of the workpiece before moving the first

and second annular cutters and the workpiece axially relatively to the first and second annular cutter such that the first annular cutter cuts the concave shaped aerofoil surface in one face of the slot and the second annular cutter cuts the convex shaped aerofoil surface on the opposite face of the slot.

31. A method substantially as hereinbefore described with reference to the accompanying drawings.

32. An apparatus substantially as hereinbefore described with reference to a and as shown in the accompanying drawings.

Patents Act 1977 **Ex niner's report to the Comptroller under Section 17 (The Search Report)** -16-	Application number GB 9306972.2

Relevant Technical fields (i) UK Cl (Edition L) B3K (ii) Int Cl (Edition 5) B23C	Search Examiner V L C PHILLIPS
Databases (see over) (i) UK Patent Office (ii)	Date of Search 14 MAY 1993

Documents considered relevant following a search in respect of claims 1-32

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

Category	Identity of document and relevant passages	Relevant to claim(s)

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